NASA Technical Memorandum 86795

A Flightpath Overshoot Flying Qualities Metric for the Landing Task

Donald T. Berry

January 1986

NASA
National Aeronautics and
Space Administration

NASA Technical Memorandum 86795

A Flightpath Overshoot Flying Qualities Metric for the Landing Task

Donald T. Berry
Ames Research Center, Dryden Flight Research Facility, Edwards, California

1986

NASA
National Aeronautics and
Space Administration
Ames Research Center
Dryden Flight Research Facility
Edwards, California 93523

A Flightpath Overshoot Flying Qualities Metric for the Landing Task

Donald T. Berry*
NASA Ames Research Center
Dryden Flight Research Facility
Edwards, California

Abstract

An analysis was conducted of the attitude and flightpath angle response of configurations used in the Total In-Flight Simulator (TIFS) pitch-rate command systems program. The results show poor correlation between pilot ratings and attitude response and indicate that attitude was not a major influence in the results. A strong correlation was found to exist, however, between the amount of flightpath angle peak overshoot and the pilot ratings. This correlation is similar to the best correlations that have been obtained in recent closed-loop and time-domain analyses but has the advantage of greatly simplified implementation and interpretation.

Nomenclature

DB	attitude dropback, deg (Fig. 1)
h	altitude
q	pitch rate, deg/sec
q_m	maximum pitch rate, deg/sec
PR	pilot rating
T_{θ_2}	pitch-attitude numerator time constant, sec
TIFS	Total In-Flight Simulator
α	angle of attack, deg
γ	flightpath angle, deg
γ_P	flightpath angle at peak overshoot, deg
γ_R	flightpath angle at control release, deg
θ	pitch attitude, deg
θ_R	pitch attitude at control release, deg
θ_{SS}	pitch attitude during steady state, deg
τ	time constant, sec
ω_n	short-period dominant mode natural frequency, rad/sec

*Aerospace Engineer, Flight Operations and Research Division. Associate Fellow, AIAA.

Introduction

In recent years, virtually all advanced aircraft have utilized pitch-rate command flight control systems. It is well known in the flying qualities community that pilots newly introduced to pitch-rate command flight control systems have a strong tendency to float or balloon on landing. Some analysts believe this is because of the attitude-hold tendency of these systems and is only a familiarization problem that can be overcome with modest training. Others think that these systems have a basic flying qualities deficiency and should be designed to have characteristics more like conventional aircraft. In most cases, problems of this nature are not adequately resolved in ground-based simulators because of the complex interaction of visual and motion cues and pilot stress in an actual landing environment.

Because of the paucity of flight data taken under controlled conditions applicable to these situations, a Total In-Flight Simulator (TIFS) program was undertaken to enlarge the flight data base.[1] Analysis of the results of Ref. 1 did not correlate well with established flying qualities criteria. However, time history analyses based on angle of attack (α) and normal acceleration at the pilot location (NZP), and analyses based on altitude and altitude-rate pilot loop closures did provide promising results.[1,2]

Despite the success of the altitude and altitude-rate pilot loop closures, a time history approach has much appeal because data can be analyzed directly from simulator or flight responses. It is especially adaptable to specification and evaluation criteria requirements. It also provides flexible guidelines for flight control system design. Although the α-NZP time history criterion proposed in Ref. 1 provided good correlation, it relies on a somewhat complex equation that consists of several terms involving the initial angle-of-attack slope, intermediate angle-of-attack slope, first NZP peak value, second NZP peak value, and a weighted value of the time to reach steady-state angle of attack. In addition, it is not directly pilot-centered in that angle of attack is not visible to the pilot and cannot be used as a direct cue. It would seem that attitude and altitude rate or flightpath angle would be better time history parameters because the pilot can perceive these. Reference 1 acknowledges this by pointing out that angle of attack may be a surrogate for flightpath. However, it would seem better to use the primary variable rather than a surrogate.

This study was undertaken, therefore, to determine if pilot-centered time-domain variables provide good correlation with the data base of Ref. 1. A summary of the Ref. 1 configurations and results is presented in Table 1.

Procedure

At the outset, an attempt was made to use heuristic reasoning to choose the most promising time-domain variables for a preliminary analysis of the data. Pilots most frequently use the terms attitude, altitude, rate of descent, and flightpath angle when describing their cues in approach and landing tasks. However, these terms are used in a piloting sense and cannot always be interpreted in terms of strict engineering definitions. The use of attitude by the pilot during landing approaches has been well established analytically, but its role during flare and touchdown is less well understood. During flare and touchdown, pitch-rate command systems typically evoke comments on float tendencies, which suggests a perception of the rate of descent, flightpath angle, and height above the runway (altitude). Rate of descent, flightpath angle, and altitude are directly related; hence, considering any one of them is probably adequate for a first analysis. Flightpath angle is generally considered more fundamental by most analysts and therefore, in addition to attitude, is a reasonable choice for analysis. Consequently, attitude and flightpath angle were chosen for initial analysis.

Attitude Analysis and Discussion

The data base was first analyzed from the point of view of attitude dropback (DB) and overshoot of pitch attitude as defined by Ref. 3 (Fig. 1). These concepts could be applied in a straightforward manner to most of the pitch-attitude responses (Fig. 2). However, a few of the attitude responses had no steady-state value. Instead, they exhibited a continuously increasing dropback after the peak value was attained (Fig. 3). Consequently, the values of dropback and overshoot were normalized by dividing by the value at control release. The configurations that had no steady state tended toward a value of zero. They were therefore arbitrarily assigned a normalized value of 1 and flagged when plotted (Fig. 4).

Results of the attitude dropback analysis (Fig. 4) show that most of the configurations had very little overshoot (negative dropback) or dropback. Only the washout and conventional configurations had dropback greater than 0.25. The configurations with continuously increasing dropback are plotted on the left-hand axis and flagged. Reference 3 indicates that attitude dynamics are satisfactory if there is no overshoot and if dropback is not excessive. This is true if the configurations meet requirements on frequency and damping, which these data do.[1] To achieve satisfactory attitude dynamics, some pitch-rate overshoot is required, but not necessarily very much. Pitch rate, of course, transforms into pitch attitude by way of integration. All the configurations had some pitch-rate overshoot.

The correlation between pilot rating (PR) and the amount of attitude dropback was poor — 54 percent of the data were within a ±1.0 PR band, and 86 percent were within a ±1.5 PR band. There is a tendency for the ratings to degrade as dropback becomes negative (overshoot), as predicted in Ref. 3. However, the large spread in pilot ratings, particularly in the zero dropback region, indicates that attitude response was not a major factor in the pilot ratings. This result is in agreement with Ref. 1 that showed poor correlation between the results and classical attitude criteria such as Neal-Smith[4] and equivalent systems.

Flightpath Analysis and Discussion

None of the flightpath angle responses had a steady-state value, because all configurations had a gradual decrease in flightpath angle (γ) after the peak value (γ_P) was attained (Figs. 2 and 3). Therefore, it was decided to use the value at control release (γ_R) and the peak value as parameters for flightpath angle response (Fig. 5). This is convenient both from an analytical and a pilot-centered point of view. It is easily determined from a boxcar command input, and it is a reasonable pilot-control strategy (pull on the stick to achieve a comfortable pitch rate, and then release it when the desired flightpath angle is achieved). A 5-sec boxcar command was used because Ref. 1 documents the configurations with this input. The difference between the peak and release values was proportioned to the release value and expressed as a percent peak overshoot in flightpath angle (Fig. 5). Hence,

$$\gamma \text{ peak overshoot (percent)} = \frac{\gamma_P - \gamma_R}{\gamma_R} 100$$

Because all the pitch-attitude peak responses were only slightly larger than the values at control release, it was clear that this technique should not be applied to pitch attitude.

Figure 6 shows pilot ratings as a function of flightpath angle peak overshoot — 77 percent of the ratings were within a ±1 PR band, and 95 percent were within a ±1.5 PR band. This correlation is quite remarkable when one considers the simplicity and ease of applying the metric. The reason for this correlation may be that flightpath angle peak overshoot is an indication of the predictability of flightpath response. This is very important to the pilot in the landing task. If the aircraft acquires — with little or no overshoot — the flightpath that the pilot sees on neutralizing the controls, he can readily predict the response. On the other hand, if the aircraft significantly overshoots the flightpath angle that the pilot sees when he releases the controls, it is difficult for him to anticipate the response.

The characteristics of flightpath response after the peak overshoot value were also examined. As previously mentioned, all configurations exhibited a gradual change or settling in flightpath angle after the peak value was attained. This is because a change in angle of attack was brought about by the speed bleedoff during the pullup command. The settling is an indication of the amount of aft stick that the pilot needs during the landing maneuver. Reference 1 indicates that, because conventional aircraft require a noticeable amount of aft stick during the landing maneuver, aft stick is an important factor in the handling qualities.

The settling in flightpath angle was minimal for the typical pitch-rate command configurations (Fig. 2), but was more pronounced for the conventional aircraft configuration (Fig. 3) and the washout configurations (Fig. 7). In the case of the pitch-rate command systems, the settling was minimized by their attitude-hold tendencies. It was noted that prefilters (Fig. 8), as well as washout (Fig. 7), reduced the flightpath overshoot ratio when applied to a typical pitch-rate command system (Fig. 2). However, prefilters (Fig. 8) did not increase the amount of flightpath settling, whereas washout (Fig. 7) did.

A comparison of data from configurations with prefilter added and with washout added is presented in Fig. 9. Conventional and canard configurations are included for reference. The trend line from Fig. 6 is superimposed on these data. All the basic configurations (circles), basic configurations plus lead/lag (squares), and basic configuration plus lead/lag plus canard (quarter-circle) had a minimum of flightpath settling, which is typical of pitch-rate command systems. All the washout configurations (diamonds and triangles) had flightpath settling representative of a conventional aircraft (elongated diamond). Nevertheless, it can be seen that all the data follow the same trend line, and flightpath peak overshoot is clearly the dominant influence. This indicates that the decrease in flightpath peak overshoot, and not the increase in flightpath settling, is responsible for the improvement in pilot ratings. It appears that flightpath settling and the associated monotonic stick forces are much less important factors than proposed in Ref. 1.

Figure 9 also illustrates how well the flightpath peak overshoot parameter correlates what seem to be a variety of unrelated configuration effects. Conventional aircraft, superaugmented aircraft, space shuttle-like aircraft, various combinations of lead/lag and washout filters, and even the canard configuration can be explained in terms of flightpath peak overshoot. The canard configuration was thought to be influenced by NZP effects associated with the change in center of rotation. Figure 9 indicates that these influences were small in comparison to flightpath peak overshoot.

Figure 10 shows a direct comparison between the flight results of Ref. 1, the ratings predicted by the α-NZP time-domain technique of Ref. 1, the ratings predicted by the altitude (h) closure technique of Ref. 2 that used an altitude outer loop closure and an attitude inner loop closure, and the ratings predicted by the results of this analysis. (Rating predictions from the results of this analysis were obtained using the central trend line from Fig. 6.) It can be seen that the rating predictions are in general agreement, and in most cases they track the flight data fairly well. The largest disagreement between flight results and the flightpath criterion is configuration s, where a 2.5 PR error exists. The worst comparison for the α-NZP criterion is configuration r, where the discrepancy is a ΔPR of 2.75. The worst case for the altitude closure analysis is configuration u, where a ΔPR of 6 exists. Figure 11 presents this information in histogram form. It can be seen that the flightpath criterion gives somewhat better results overall, despite the fact that it is considerably easier to implement and interpret than the other techniques.

With regard to Fig. 6, it is worth noting that the study of Ref. 1 was essentially eight subexperiments. The study considered the influence of several different parameters – $1/T_{\theta_2}$ (where T_{θ_2} is the pitch-attitude numerator time constant), dominant mode frequency, conventional response, superaugmentation, shuttle dynamics, rate command, prefilters, washout, static stability, and canards – in the landing task. This wide diversity of influences can be explained in terms of one relatively simple unifying parameter. Of course, until other data bases are analyzed, these conclusions must be limited to the range of parameters considered in Ref. 1. Nevertheless, the general conclusions reached here seem very convincing and should aid in the analysis of other landing data.

Concluding Remarks

An analysis was made of the attitude and flightpath angle response of configurations used in the Total In-Flight Simulator (TIFS) pitch-rate command study. Results indicate that the attitude response was generally satisfactory for all configurations and therefore not a factor in the pilot-rating results. A very strong correlation was found to exist between the amount of flightpath angle peak overshoot and the pilot ratings. The correlation was valid for all configurations despite a diversity of configurations that included conventional aircraft, space shuttle dynamics, superaugmented aircraft, neutral static stability, prefilters, and canards. In comparison to the influence of flightpath angle peak overshoot, expected influences such as monotonic stick forces and initial acceleration at the pilot station were negligible. The correlation was similar to the best correlations that have been obtained in recent closed-loop and time-domain analyses, but has the advantage of greatly simplified implementation and interpretation.

References

[1]Berthe, C.J.; Chalk, C.R.; and Sarrafian, S.: Pitch Rate Flight Control Systems in the Flared Landing Task and Design Criteria Development. NASA CR-172491, Oct. 1984.

[2]Sarrafian, S.K.; and Powers, B.G.: Application of Frequency Domain Handling Qualities Criteria to the Longitudinal Landing Task. NASA TM-86728, Aug. 1985.

[3]Gibson, J.C.: Piloted Handling Qualities Design Criteria for High Order Flight Control Systems. AGARD CP-333, Criteria for Handling Qualities for Military Aircraft, June 1982.

[4]Neal, T.P.; and Smith, R.E.: An In-Flight Investigation To Develop Control System Design Criteria for Fighter Airplanes. AFFDL TR-70-74, vol. 1, Dec 1970.

TABLE 1. — DESCRIPTION OF CONFIGURATIONS

Configuration	ω_n, rad/sec	$1/T_{\theta_2}$, sec-1	Description	Pilot rating (average)	Reference 3 configuration number
a	2.8	0.38	Rate command	6.0	1-1-1
b	2.7	1.00	Rate command	4.5	1-3-7
c	1.8	0.38	Rate command	6.0	2-1-1
d	1.8	0.72	Rate command	3.8	2-2-2
e	τ = 0.4 sec	0.38	Neutral static	5.8	3-1-3
f	τ = 0.4 sec	0.72	Neutral static	3.8	3-2-4
g	2.8	0.38	Rate command (a) plus lead/lag	3.8	4-1-1
h	2.8	0.72	Rate command plus lead/lag	2.5	4-2-2
i	2.7	1.00	Rate command (b) plus lead/lag plus washout	4.0	4-3-7-1
j	1.8	0.38	Rate command (c) plus lead/lag	4.5	5-1-1
k	1.8	0.72	Rate command (d) plus lead/lag	2.5	5-2-2
l	2.3	0.38	Superaugmented	5.0	6-1-1
m	2.3	0.38	Superaugmented (l) plus washout	3.0	6-1-1-1
n	2.3	0.38	Superaugmented (l) plus lead/lag	3.7	6-2-1
o	2.3	0.38	Superaugmented (l) plus lead/lag plus washout	3.0	6-2-1-1
p	2.8	0.72	Conventional aircraft	2.8	7-1-4
q	1.5	0.40	t′ plus lead/lag	5.2	8-1-5
r	1.5	0.40	t′ plus lead/lag plus washout	2.0	8-1-5-1
s	1.1	0.40	Modified shuttle	7.7	8-2-5
t	1.5	0.40	Shuttle-like	6.7	8-3-5
u	1.5	0.40	Shuttle-like (t) plus washout	3.0	8-3-5-1
v	1.5	0.40	t′ plus lead/lag plus canard	1.0	8-4-6

The term ω_n is the short-period dominant mode natural frequency; T_{θ_2} is the pitch-attitude numerator time constant; τ is the time constant. The t′ configuration is the shuttle-like t configuration minus a 47-msec time delay.

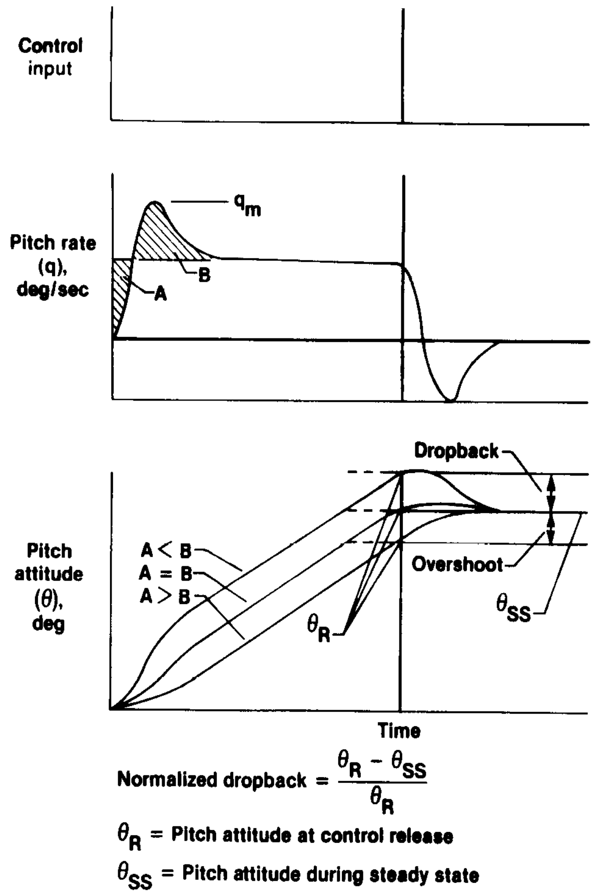

Fig. 1 Attitude response analysis features.

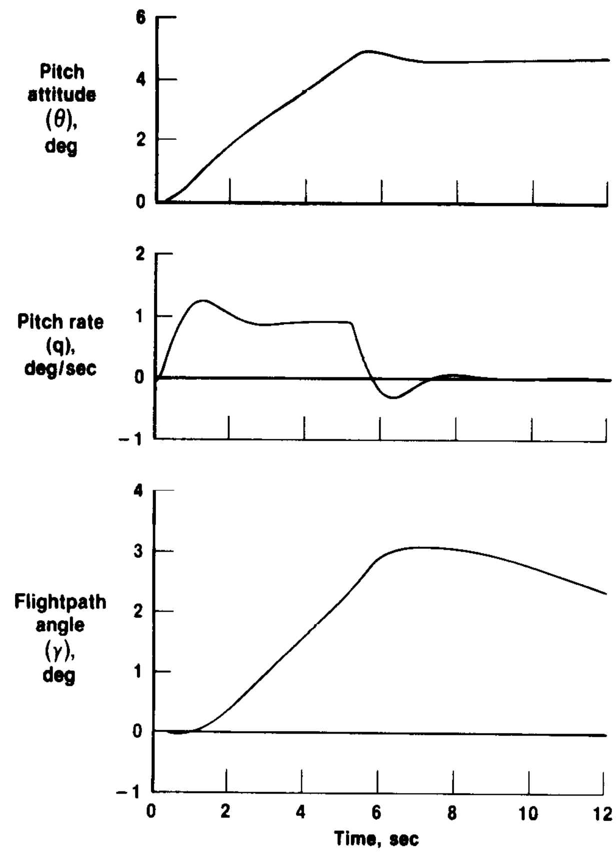

Fig. 2 Typical response for pitch-rate command system (Ref. 1), 5-sec boxcar command input.

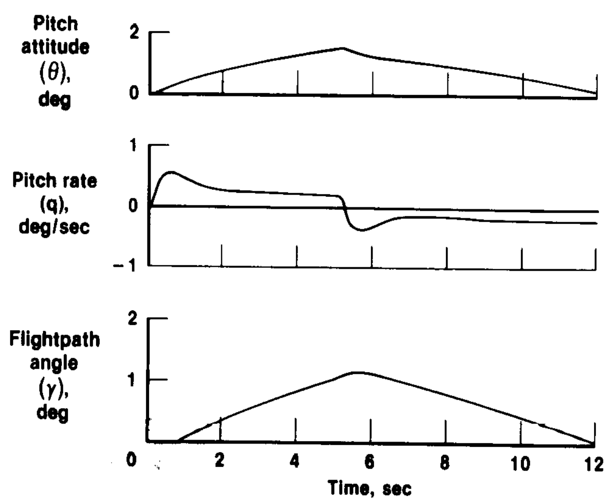

Fig. 3 Typical response for conventional aircraft (Ref. 1), 5-sec boxcar command input.

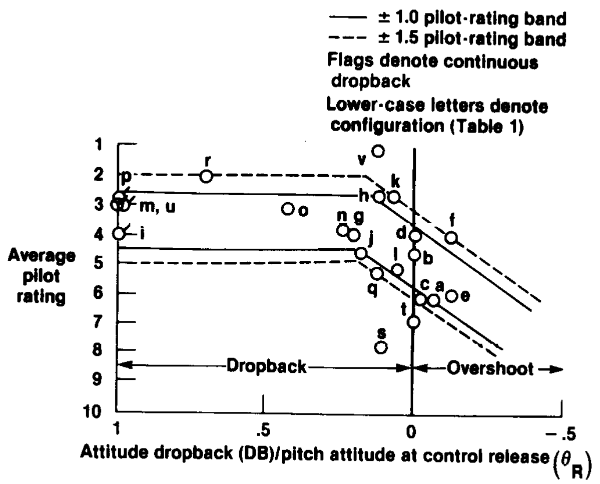

Fig. 4 Pilot ratings as a function of normalized attitude dropback.

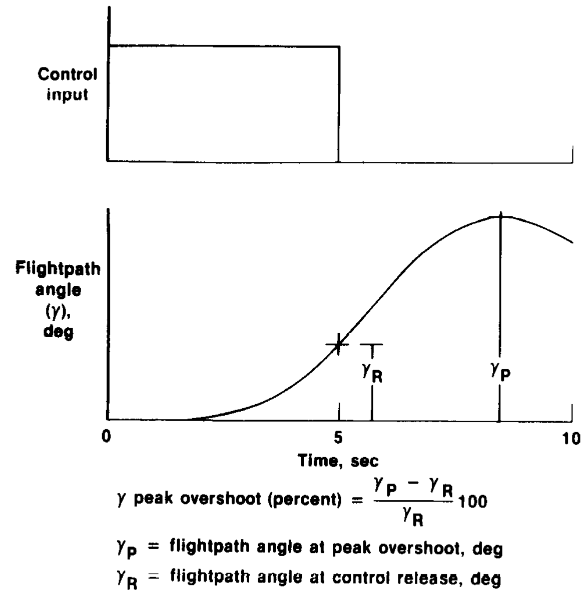

Fig. 5 Flightpath angle response features.

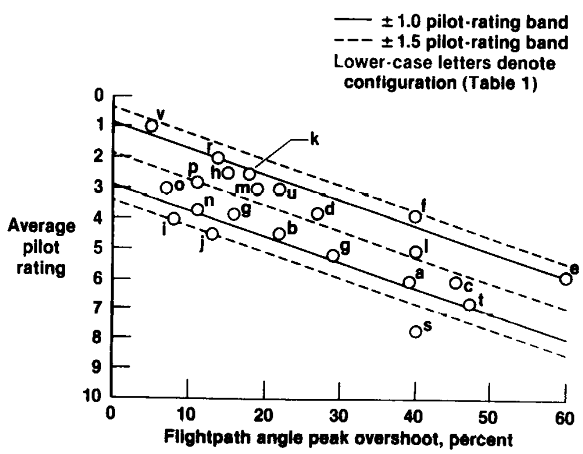

Fig. 6 Pilot ratings as a function of flightpath angle peak overshoot.

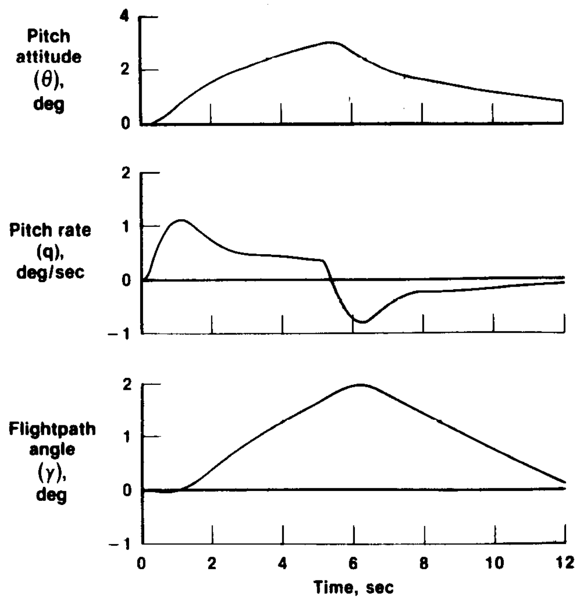

Fig. 7 Typical response for pitch-rate command with washout filter (Ref. 1), 5-sec boxcar command input.

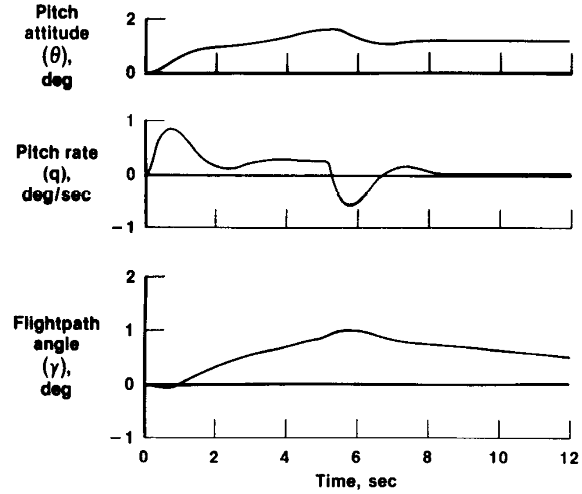

Fig. 8 Typical prefilter rate command aircraft response (Ref. 1), 5-sec boxcar command input.

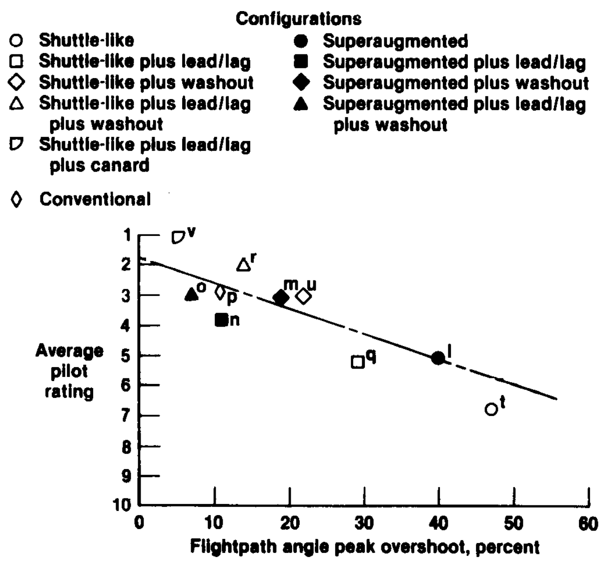

Fig. 9 Pilot ratings for selected configurations.

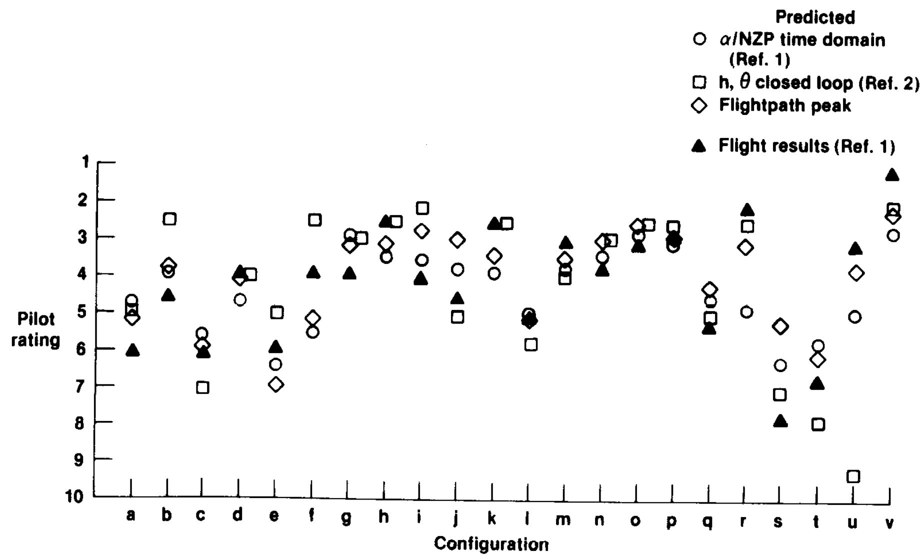

Fig. 10 Comparison of flight results and predictions (Table 1).

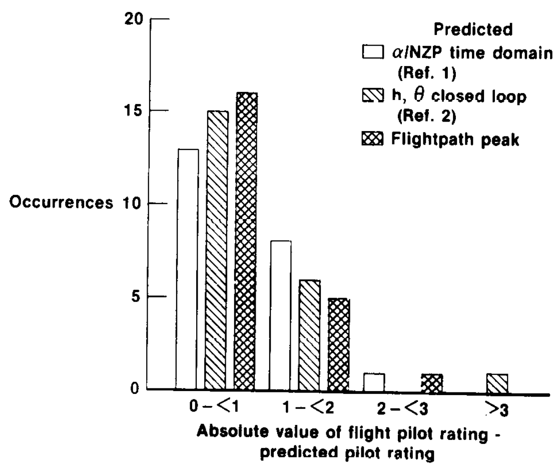

Fig. 11 Pilot-rating prediction error histogram.

1. Report No. NASA TM-86795	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle A Flightpath Overshoot Flying Qualities Metric for the Landing Task		5. Report Date January 1986
		6. Performing Organization Code
7. Author(s) Donald T. Berry		8. Performing Organization Report No. H-1322
9. Performing Organization Name and Address NASA Ames Research Center Dryden Flight Research Facility P.O. Box 273 Edwards, CA 93523-5000		10. Work Unit No. RTOP 505-34-01
		11. Contract or Grant No.
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546		13. Type of Report and Period Covered Technical Memorandum
		14. Sponsoring Agency Code

15. Supplementary Notes

Prepared as AIAA Paper 86-0334 for presentation at AIAA 24th Aerospace Sciences Meeting, Reno, Nevada, January 6-9, 1986.

16. Abstract

An analysis was conducted of the attitude and flightpath angle response of configurations used in the Total In-Flight Simulator (TIFS) pitch-rate command systems program. The results show poor correlation between pilot ratings and attitude response and indicate that attitude was not a major influence in the results. A strong correlation was found to exist, however, between the amount of flightpath angle peak overshoot and the pilot ratings. This correlation is similar to the best correlations that have been obtained in recent closed-loop and time-domain analyses but has the advantage of greatly simplified implementation and interpretation.

17. Key Words (Suggested by Author(s)) Flightpath, Handling qualities, Landing task, Superaugmented aircraft	18. Distribution Statement Unclassified — Unlimited. STAR category 08

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified	10	A02

*For sale by the National Technical Information Service, Springfield, Virginia 22161.